POLAR PATROL BALLOON PROJECT IN ANTARCTICA

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Abstract: We are planning to carry out a circumpolar ballooning project called "Polar Patrol Balloon (PPB)" project. The main objective of the PPB project is to establish a station network at altitudes higher than 30 km over the Antarctic for the studies of upper atmosphere physics, cosmic ray physics, meteorology and glaciology. Feasibility studies of the project and the development of new technology for long-duration flight have been commenced in April 1984 by the PPB working group organized in the National Institute of Polar Research. By using zero-pressure balloons with an auto-ballasting system, it is expected that PPB launched from a station in Antarctica will land near the launching site about three weeks later with meridional deviation less than about $\pm 2°$ in the case of a midsummer 30 km-level flight. This paper gives an outline of this project.

1. Introduction

The first implication to a concept of the circumpolar ballooning experiment over the Antarctic was given by the project GHOST (Global Horizontal Sounding Technique, 1969), in which a number of superpressure balloons launched from New Zealand circled the southern hemisphere between 30° and 60°S at a constant density level of $\sim$200 mb ($\sim$12 km) for the order of month. Such long-duration flights suggest that a stable polar vortex is dominant in the southern hemisphere and thus serving to build up a favorable stratospheric condition for keeping balloons at ceiling altitudes for a long period of time. This good wind condition in the stratosphere has also been confirmed by success of similar balloon campaigns after the GHOST: EOLE (MOREL and BANDEEN, 1973), TWERLE (TWERE Team, 1977; LEVANON, 1982), MAP-MIR (TALAGRAND, 1983) and EMA (HOLZWORTH, 1983). The launching sites of these balloon campaigns, however, were located at low latitudes. Therefore, the balloons rarely traversed over Antarctica. Furthermore, the ceiling altitudes of these balloons were usually less than 25 km, which were too low to observe bremmstrahlung X rays and electric fields associated with auroral phenomena. Under these circumstances the National Institute of Polar Research has embarked on a new advanced

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project called the "Polar Patrol Balloon (PPB)" project. The main objective of the PPB project is to establish a station network at altitudes higher than 30 km over the Antarctic for the studies of upper atmosphere physics, cosmic ray physics, meteorology and glaciology. It is quite difficult to establish a dense network of stations on the ground in Antarctica, particularly in the inland area. As described in the following, there is a possibility that the PPB project solves this problem. The PPB project will use zero-pressure balloons with volume of 15000 m^3 or more since it seems to be difficult to develop high-altitude and heavy-payload supperpressure balloons. It is expected that zeropressure balloons launched from any places in Antarctica would circle along a constant geographic latitude at an isobar level of less than 10 mb. Figure 1 shows the expected trajectories of PPBs launched from Syowa, McMurdo and St. Georgia Stations in the austral summer season. They are like circles with different

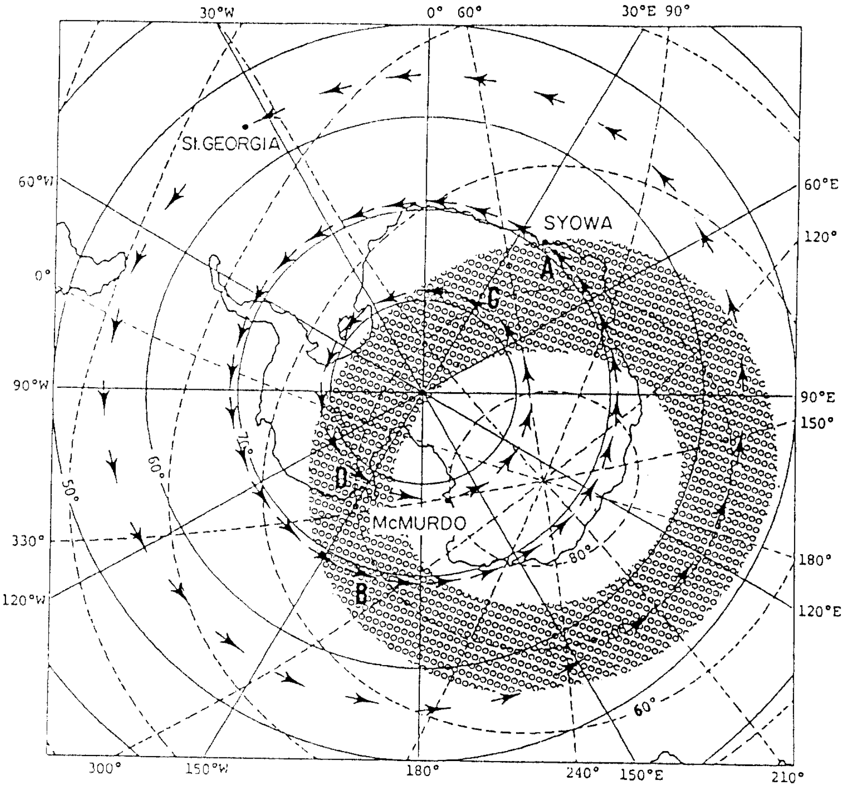

Fig. 1. Expected trajectories of PPBs launched from Syowa, McMurdo and St. Georgia Stations in the austral summer season. The auroral zone is shown by hatched area.

diameters and never intercross with each other. Note the interesting relation of these circular orbits to the auroral zone indicated by hatched area in Fig. 1. The global survey of auroral phenomena will be accomplished easily over the whole auroral oval, if simultaneous flights of two PPBs or more are carried out. For example, a PPB network of four balloons, two each launched from Syowa (A and B in Fig. 1) and McMurdo (C and D), will provide important information on latitudinal and longitudinal dependences of auroral phenomena as well as their temporal characteristics. These characteristics of the PPB network will be hardly achieved by other techniques such as spacecraft and sounding rocket.

In the following sections, the results of the feasibility studies concerning meteorological conditions, balloon technology and scientific program are presented.

2. Meteorological Feasibility

The feasibility of a long-duration circumpolar flight must be examined first from meteorological conditions. There are two basic problems; a) visible and infrared radiations, and b) stratospheric wind.

2.1. *Visible and infrared radiations*

A possible change of the balloon volume in flight, which is caused by filling-gas temperature change, concerns directly with the balloon life since the altitude of the zero-pressure balloon is controlled by the auto-ballast system. The minimum amount of ballast neccessary for a constant-level flight depends on amplitude of gas temperature changes which are caused by variations in visible and infrared radiations, upward and downward. Therefore, temporal and spatial characteristics of the radiations must be searched as widely as possible over the Antarctic in order to determine the optimum values of balloon size and payload weight. It is suggested first that the PPB experiment should be carried out around midwinter or midsummer because there is no sunrise nor sunset during these seasons. Further, a large difference between the

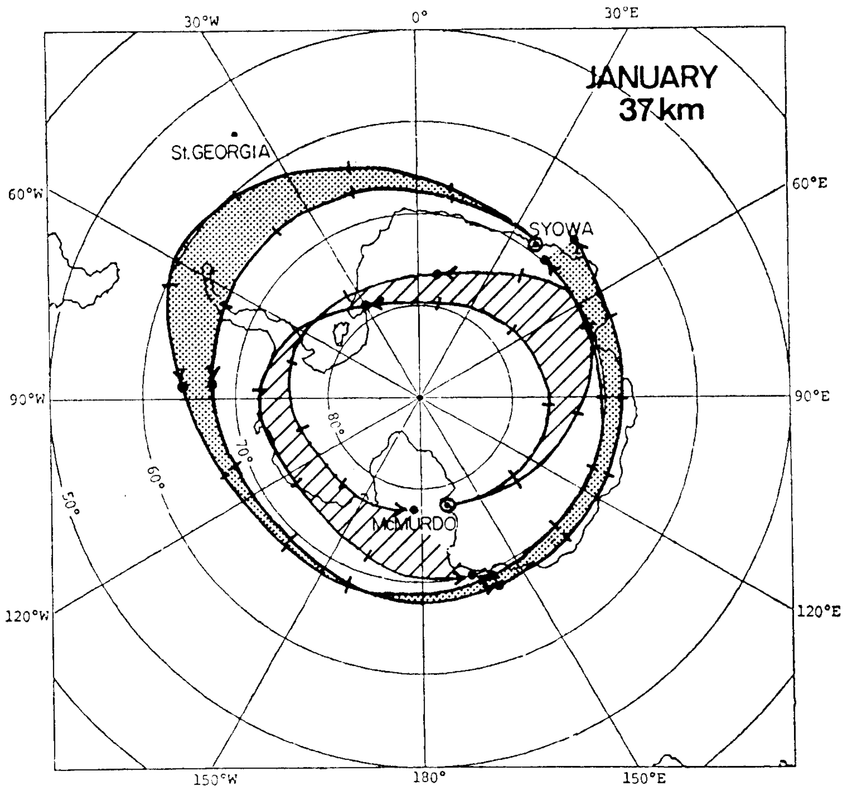

Fig. 2a. Predicted trajectories of PPBs launched from Syowa and McMurdo Stations in the austral midsummer. The trajectories are calculated based on the weekly 5 mb northern hemisphere charts in the period of July 7–21, 1976 presented by NASA (1978). The locations every day are indicated by tick marks.

albedo radiation from the continent covered by snow and ice and that from the sea affects seriously the balloon life. Radiation data obtained from the NOAA and GMS satellites will assist the overall estimation of radiation distributions in the southern hemisphere.

2.2. Stratospheric wind

The trajectory of PPB is determined mainly by wind velocity and direction in the stratosphere. By assuming that the stratospheric wind system is the same between the northern and southern hemispheres, the most probable flight trajectories of PPBs launched from Syowa and McMurdo Stations have been estimated based on the radiosonde data obtained from the northern hemisphere. Figure 2 gives the results of estimation in the cases of summer and winter flights, respectively, where the uncertainty of estimation is indicated by hatched areas. It is found that the circumpolar orbit is fairly well performed in the austral summer (January), while the north-south deviation of the balloon orbit is quite large in the austral winter (July). The period of a circumpolar flight depends on latitude and altitude. Listed in Table 1 are the circumpolar flight periods along 70°S and the maximum north-south deviations after one circumpolar flight. It is found that a summer flight at the 30 km level, which is the most realistic case, takes about twenty days for one circumpolar flight, while the north-south deviation is only within $\pm 2°$ after one circumpolar period. For reference

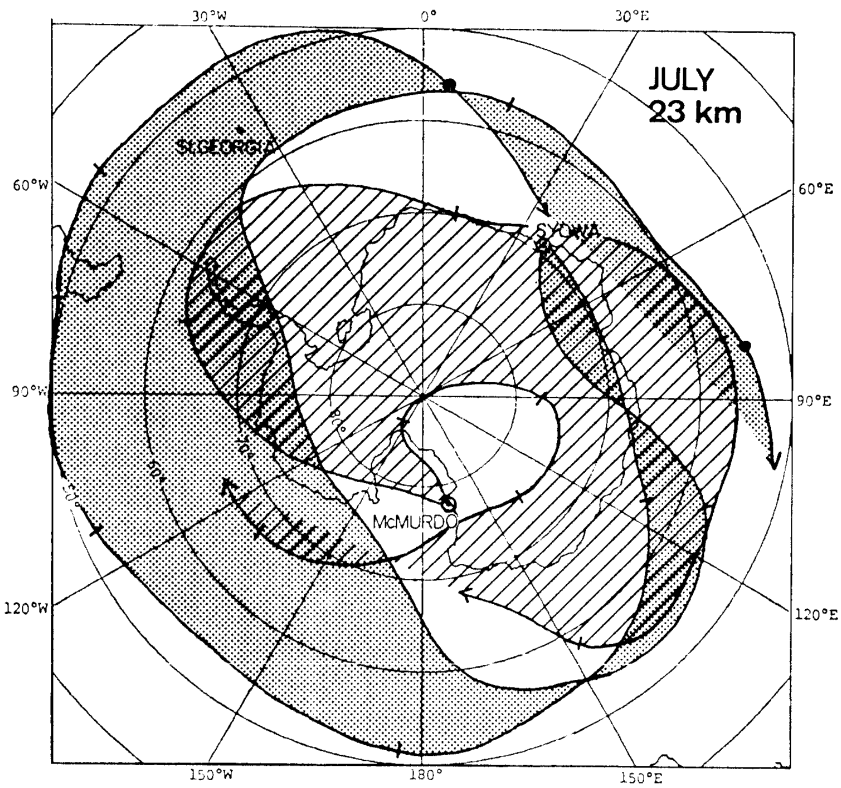

Fig. 2b. Predicted trajectories of PPBs launched from Syowa and McMurdo Stations in the austral winter. The trajectories are calculated based on the daily 30 mb northern hemisphere charts in the period of December 1–5, 1982 presented by Institut für Meteorologie, der Freien Universität Berlin *(1983).*

Table 1. Expected circumpolar flight period and north-south deviation after one circumpolar flight.

Altitude (km)	Summer (January)		Winter (July)	
	period (days)	north-south deviation	period (days)	north-south deviation
40	10 W	±2°	3 E	±10°
35	12 W	±2°	3 E	± 7°
30	22 W	±2°	3 E	± 6°
25	52 W	±2°	4 E	± 5°
20	— —	—	6 E	± 5°
15	39 E	±2°	8 E	± 4°

E: Eastward, W: Westward.

Table 2. Balloon flight data obtained from the GHOST, EOLE, TWERLE and MAP-MIR projects.

Project name	Experiment date	Altitude	Latitude	Circumpolar fllight period
GHOST	1966–70	200 mb (12 km)	45°S±15°	12 days
EOLE	Sep. 1971	200 mb (12 km)	30°S±15°	14–21
TWERLE	Sep.–Oct. 1975	150 mb (14 km)	60°S±15°	8
MAP-MIR	Dec.–Jan. 1982	15–35 mb (~25 km)	20°S±10°	50

the flight results of the GHOST and other three projects are summarized in Table 2.

3. Balloon Technology

New balloon technology such as auto-ballasting system, balloon tracking and data acquisition and power supply must be developed for the success of the PPB project, as well as the feasibility study of meteorological conditions. It is scheduled that these techniques are developed for five years from 1984 to 1988.

3.1. Auto-ballasting system

In a regular balloon flight over mid-latitudes, it is necessary to consume ballast of about 10% of the total weight in order to compensate the lift difference between daytime and nighttime. However, much smaller amount of ballast is enough if the balloon encounters neither sunrise nor sunset. As a rough assumption, it is expected that the radiation differences among over the continent, over the sea and over the cloud are about 1/10 of the day-night difference. Therefore, the balloon maintains the flight level over probably one month around midsummer or midwinter by mounting ballast of about 30% of the total weight.

Since PPB is out of the direct telecommand range for most of the time, we will use an auto-ballasting system. We have already developed a standard auto-ballasting system by using a high-sensitive balloon ascentmeter and an on-board micro-processor (NISHIMURA and HIRASAWA, 1981). We are now developing a new system using a high-sensitive barometer in order to minimize the ballast consumption. The first flight test of the latter system has been successfully performed in May 1984 in Japan.

3.2. *Balloon tracking*

The tracking of balloon's location throughout the flight is most important for the PPB project. There are two methods of balloon tracking: one from a network of multiple ground telemetry stations (GHOST, TWERLE), and the other from the balloon-satellite telemetry link (EOLE, TWERLE, MAP-MIR, EMA). The former is practicable just under the international collaboration, while the latter is easily conducted using the ARGOS system. Therefore, the latter method is considered realistic at the first stage of the PPB project.

3.3. *Data acquisition and power supply*

For acquisition of large amount of observed data, we will use an on-board memory like a satellite. In this case the stored data set is transmitted to the initial base when the balloon comes back within the telemetry range of the base. We are developing a balloon-borne data recorder with a stored memory of about 20 MB, which implies 0.5–1 MB/day (50–100 bps) for one circumploar flight at the 30 km altitude along 70°S in midsummer. On the other hand, we also hope to make an international network of tracking stations in Antarctica in order to acquire the data in real time. Combination of these two methods will be more realistic and powerful.

As an on-board power supply, LiF batteries commonly used in the scientific ballooning in Japan have capacities of about 200 Wh/kg, so that about 2 kg/day (some tens of kilograms per one flight) may be required in the case of a balloon-borne instrument consuming 20 W or so. In the midsummer flight we can expect to use a solar battery of about 100 W/m^2. Since we can assume an effective area of about (0.5 m)^2 on the balloon gondola, it follows that we obtain 20–30 W from the solar battery. In this case Pb or NiCd batteries (about 20 Wh/kg) are necessary to accumulate the power generated by the solar batteries.

4. Scientific Program

The PPB will get an advantage over other space vehicles such as rocket or satellite in the following studies.

4.1. *Meteorology*

The large-scale circulation in the stratosphere over the Antarctic can be deduced from the PPB's trajectory itself. Even if the PPB has no scientific instrument, it will serve efficiently as a floating buoy. The global distributions of ozone and NO_x will be observed by the network of PPBs. The poleward propagation of the sudden stratospheric warmings also will be observed by the PPB network. The survey of visible and infrared radiations over Antarctica and their relationships to atmospheric motions is another interesting subject.

4.2. *Upper atmosphere physics*

The global development of magnetospheric substorms will be well monitored by measuring electric and magnetic fields, bremmstrahlung X-rays and ELF-VLF emissions on multiple PPBs located at different local times and different latitudes. For example, the equipotential contours of the ionospheric electric fields as shown in Fig. 3 (MOZER and SERLIN, 1969) will be given successively like snapshot pictures, if the

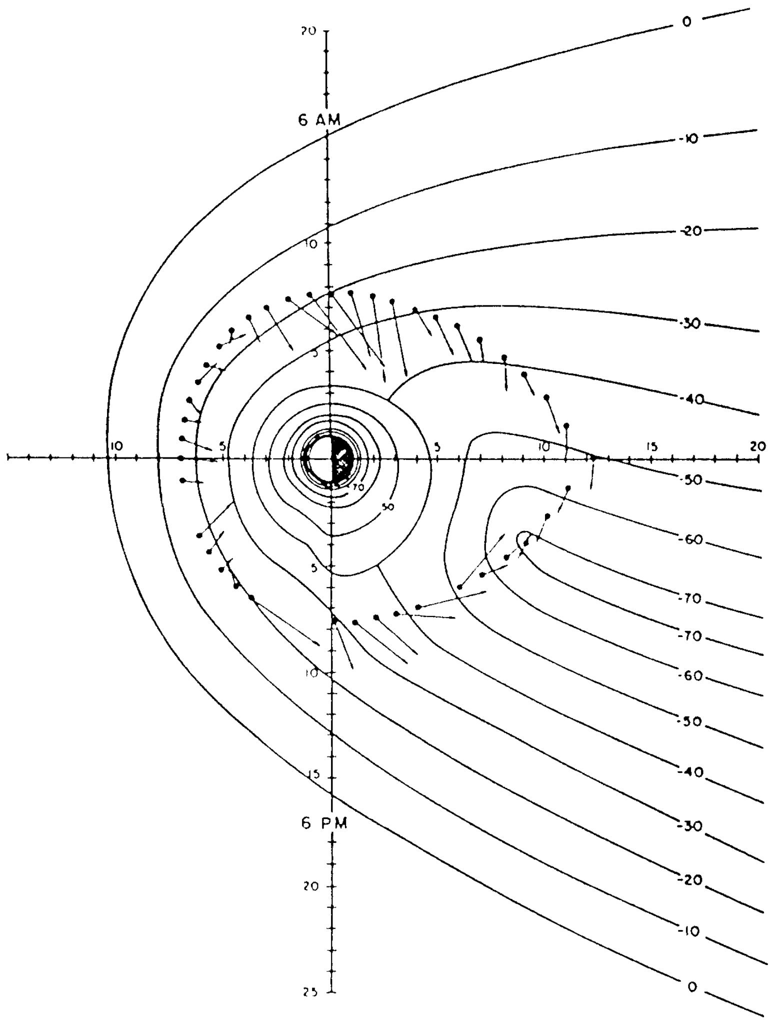

Fig. 3. *Equipotential contours on the equatorial plane in the magnetosphere, based on the electric field data measured by statatospheric balloons* (MOZER *and* SERLIN, *1969*).

multiple PPB system is established. Simultaneous observations of bremmstrahlung X-rays and ELF-VLF emissions on the network of PPBs are also important for the study of global behavior of energetic particles injected during substorms.

4.3. *Glaciology*

The accuracy of the ice-elevation map obtained in the TWERLE project was 60 m. If the accuracy is improved by the order of magnitude, these maps will contribute greatly to the study of mass balance and dynamics of the Antarctic ice sheet. Measurements of surface albedo also will be important for the study of the process of interaction between ice surface and atmosphere.

4.4. *Cosmic ray physics*

The long-duration flight of PPB is favorable for measurements of galactic gamma ray bursts and cosmic ray isotopes. From the previous balloon observations of gamma ray bursts carried out at middle latitudes, it is expected that a few events of gamma ray bursts are detectable during one circumpolar flight period. The same instrument for auroral X-ray observation can be used for measurement of gamma ray bursts when the PPB is located far from the auroral oval. Cosmic ray isotopes such as Be^7–Be^{10}, Al^{25}–Al^{28} and Fe^{55}–Fe^{60} also will be measured effectively by the PPB system.

5. Schedule and International Collaboration

The PPB project has started in 1984 under the overall management by the National Institute of Polar Research and the wide collaboration through more than ten organizations in Japan. It is scheduled to complete the PPB system in 1989 when the Japanese satellite EXOS-D will be launched. During the period from 1984 to 1989, some test flights will be conducted for developments of new techniques concerning balloon tracking, auto-control of flight level, on-board data recorder, and solar battery system, as well as physical instruments. Further, the PPB project will become more practicable if it will be carried out as an international cooperative project. A network of tracking stations is suitable for data aquisition. The coverage of the PPBs will become the entire region of the Antarctic by launching simultaneously a number of balloons at different latitudes.

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(*Received June 3, 1985*)